AFCRL-TR-75-0496

(12)

AD

ADA017205

TECHNOLOGY AND PHYSICS OF INFRARED AND POINT CONTACT DIODES

Ali Javan

Massachusetts Institute of Technology

Department of Physics

Cambridge, Massachusetts 02139

9 September 1975

Semi-Annual Technical Report #2

Approved for public release; distribution unlimited

This Research was sponsored by the Defense Advanced Research Projects Agency; ARPA Order 2618.

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AFB, MASSACHUSETTS 01731

SA #1 - AG11676

Qualified requestors may obtain additional copies from the Defense Documentation Center. All others should apply to the National Technical Information Service.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

19 REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER 18 AFCRL-TR-75-0496	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 TECHNOLOGY AND PHYSICS OF INFRARED AND POINT CONTACT DIODES.		5. TYPE OF REPORT & PERIOD COVERED Scientific Interim
		6. PERFORMING ORG. REPORT NUMBER 9 Semi Annual Technical Report, 2 no. 2,
7. AUTHOR(s) 10 Ali Javan		8. Contract or Grant # 15 F19628-74-C-0182, ARPA Order-2618
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Physics Mass. Inst. of Tech., Cambridge MA 02139		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 16 AR - 2001-01-01 61101E 17 200101
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Cambridge Research Lab Hanscom AFB, Massachusetts 01731 Contract Monitor: Audun Hordvik		12. REPORT DATE 11 9 Sep[redacted]75
		13. NUMBER OF PAGES 13
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 14 p.		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This Research was sponsored by the Defense Advanced Research Projects Agency, ARPA Order 2618.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Antenna trimming, tunneling resonances, dielectric formation, oxide studies.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Background work for this contract performed by this laboratory has shown that the tunneling characteristics of junctions formed by a very thin dielectric layer surrounded by two metals is independent of frequency (from DC through 10 μ wavelength.) These junctions may be formed by a point contact on a lightly

Micrometer

over

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Report Documentation Page.

401 735

oxidized metal surface. Principal work done this period was construction of a mathematical model for an infrared antenna/diode combination and calculation of the expected operating parameters. A closed form analytical approximation was made and experimental checks on the model validity were started. An article based on this work will be prepared. Also, the mechanism of detection of radiation by a small area thin film metal-oxide-metal structure was studied. It was shown that after subtracting thermal effects, the response at optical frequencies arises from photoemission over the oxide's potential barrier. A journal article based on this work is in preparation. Additional work was done on the I-V characteristics of a tungsten point on gold, an antenna pattern study, as well as vacuum deposited junction measurements at low temperature.

TABLE OF CONTENTS

1. SUMMARY

Background work for this contract performed by this laboratory has shown that the tunneling characteristics of junctions formed by a very thin dielectric layer surrounded by two metals is independent of frequency (from DC through 10 μ wavelength.) These junctions may be formed by a point contact on a lightly oxidized metal surface. Principal work done this period was construction of a mathematical model for an infrared antenna/diode combination and calculation of the expected operating parameters. A closed form analytical approximation was made and experimental checks on the model validity were started. An article based on this work will be prepared. Also, the mechanism of detection of radiation by a small area thin film metal-oxide-metal structure was studied. It was shown that after subtracting thermal effects, the response at optical frequencies arises from photoemission over the oxide's potential barrier. A journal article based on this work is in preparation. Additional work was done on the I-V characteristics of a tungsten point on gold, an antenna pattern study, as well as vacuum deposited junction measurements at low temperature.

2. INTRODUCTION

Preliminary work in this laboratory has determined that tunneling characteristics of metal-oxide-metal tunneling junctions across a thin dielectric layer are independent of the frequency. Calculation of operating parameters for an infrared antenna/diode combination has been completed. This shows the performance of the receiving and detecting elements as a function of geometry and dielectric constants; included is the effect of the strong frequency dependence of the circuit elements. This work will be prepared for publication. Additional measurements have been made of the antenna pattern of a printed antenna/diode. An unsuccessful search was conducted for negative resistance in a fine tungsten point on gold. Low temperature measurements were made on several vacuum deposited diodes. Junction characteristics in radiation whose photon energy is greater than the barrier height were measured and results were analyzed. A journal article based on this work is in preparation.

3. ANTENNA/DIODE CALCULATIONS

Calculation of operating parameters for an infrared antenna/diode combination has been completed. This study has been extended to include an analytical approximation of the system in closed form and evaluation of the precision of this approach. Experimental checks on the validity of our basic model are proceeding quite satisfactorily.

Previous theoretical analyses of metal-oxide-metal detectors have dealt with either the non-linearities of the junction [1,2,3] or with the antenna characteristics.[4] These theoretical results are not easily compared with measured values of detector parameters such as responsivity and noise equivalent power.

Electron tunneling across an oxide layer separating the sharply tipped tungsten wire from the (typically nickel) metal post has been recognized as the dominant (non-linear) conduction mechanism in the DC regime. It has been demonstrated experimentally that this mechanism is also responsible for rectification at least as far as the 10 μm region.[5] Devices using this principle have been used to compare harmonics of accurately known frequencies with laser sources through the infrared [6,7,8,9] and as far as 2.2 μm.[10] In practice, radiation is coupled from an electromagnetic wave to the non-linear junction by means of an antenna that, in the case of the point contact diode, is the same tungsten wire.[11]

Our model consists of an antenna with a real internal impedance and an AC voltage source. The diode is assumed to be a non-linear resistance, calculated from tunneling theory, in parallel with a capacitance determined solely by the geometry and dielectric properties of the interfacial oxide. Computed results agree qualitatively with experiment. Further work is planned to measure parameters of the high frequency roll-off of these diodes.

A closed form approximation of the equations has been derived which permits simple evaluation of maxima knees of curves and slopes. These as well as diode NEP and rectified power correspond reasonably with computed results. The enhancement of non-linearities due to the presence of zero-bias anomalies was included in the calculations. Three orders of magnitude improvement in NEP and rectified power are predicted at temperatures below 10°K due to the zero-bias anomalies.

A publication discussing these studies will be prepared.

4. ANTENNA PATTERN STUDY

The antenna pattern of a $\frac{\lambda}{2}$ printed nickel on chromium dioxide was measured at 337 μm. The maximum signal was displaced 30° from the normal to this apparently symmetric structure. Initial speculation was that reflections from the steel back-up plate were responsible, but a half inch hole cut in the plate did not significantly charge the asymmetry. Sharper beam focusing and probing the surrounding substrate revealed that pickup and rectification by the measuring probes themselves accounted for the asymmetry and for troubles in attempting to focus on the junction. Work on an antenna pattern with gold overlay demonstrated that tungsten probes penetrating the metal film an appreciable distance formed ohmic contacts. It has been found that even slightly elevated temperatures alter these junctions. As a result it was not possible to use conductive epoxy which requires heating for proper curing. The substrates were sapphire which is not wet by indium and so leads could not be fastened to the contact pads. To establish greater system symmetry a teflon lens was used instead of an off axis parabola.

5. TUNGSTEN POINT ON GOLD

The I-V characteristics of a tungsten point contact on gold was studied on a Tektronix 575 curve tracer for possible negative resistance.(12) Although the trace was not stable, no curve exhibited negative resistance or gaps where negative resistance could have existed. In the earlier experiments, the contact was controlled by a micrometer, but when this adjustment proved too clumsy to achieve junction resistance over 1000 Ω, a PZT adjustment was used and resistances of several hundred kilohms were observed. Many of these traces were not stable, but none showed evidence of negative resistance at the 120 Hz trace frequency (or above). These junctions were also probed with sip monochromatic visible argon laser lines. No correlation of diode output with wavelength was found.

6. SOLDER TECHNIQUES

It has been known for many years that indium metal will wet glass and quartz.(13,14) This characteristic has been used very effectively in sample preparation for low temperature measurements.

We have found that the best contacts are made by the following procedure: Heat a small crucible of indium just above its melting point on a hot plate over night. This produces a small amount of oxide which is disolved in the metal. Experiment has shown that stronger bonds are made with this oxide. A clean pencil soldering iron on a variac set at 60-70 v is used to apply the indium. The tip must be free of lead and tin to obtain a good bond.

7. LOW TEMPERATURE MEASUREMENTS ON DEPOSITED JUNCTIONS

During this half year, work was done on magnesium-lead, tin-tin and aluminum-aluminum junctions. The mask described in our previous report was

used this time except that the 5 μm wide slits were etched to a width of 50 μm. Silicon monoxide has been used particularly with magnesium to slow junction change after removal from the evaporator.

$Al\text{-}Al_2O_3\text{-}Pb$ junction second derivative $\frac{d^2 i}{dv^2}$ characteristics were recorded showing voltages of the tunneling resonances with measurement resolution better than 10 mv at liquid nitrogen and liquid helium temperatures. Comparison of liqued nitrogen traces at 10 MHz and X-band gave positions and half power line width of the 300 mv resonance identical within better than 10 mv. Thus the relaxation times of these phenomena must be considerably shorter than 100 psec. Experiments are underway to extend these measurements to the far infrared region.

The zero-bias resonance of $Cr\text{-}Cr_2O_3\text{-}Ag$ was recorded at liquid nitrogen temperature at 10 MHz, 500 MHz and X-band. We can infer relaxation times of a fraction of a nonosecond from these data. Zero-bias anomalies over 20 percent due to impurity doping or interface defects have been observed at liquid helium temperatures.

8. MECHANISM OF RADIATION DETECTION IN THE VISIBLE

The response to visible radiation of a small area thin film metal-oxide-metal (MOM) structure as well as that of a mechanical metal-to-metal point contact diode, has been published.[15,16,17,18] For these, different possible mechanisms have been discussed, including optical rectification due to the nonlinear character of the electron tunneling process; this rectification process would be similar to that occurring at the infrared and the lower frequencies. The results of our experiments on high-speed (small area) thin-film vacuum-deposited junctions show that the response to optical frequencies arises from photoemission over the oxide's potential barrier and

has the same origin as that observed sometime ago in a slow-speed, large area junction.[19] At lower frequencies, however, the mechanism must arise from a rectification process dominated by the nonlinear I-V characteristic due to electron tunneling across the junction.

In the experiment, the response of the MOM junction at room temperature to the visible radiation obtained from an argon laser is studied as a function of a bias voltage applied to the junction and the frequency of the incident radiation. Six different lines of the argon laser ranging from 4579 Å to 5145 Å are used. The measurement technique adopted in the experiment discriminates against spurious signals appearing across the junction due to thermal effects which have a long time constant (exceeding about 100 μsec). The results are then compared to the rectification of a radio-frequency signal observed in the same junction versus a bias voltage.

The studies are made on an Al-Al_2O_3-Al junction, fabricated by vacuum deposition through a mechanical mask. An Al strip 20 μ wide and 1000 Å thick is first deposited and, after oxidation by exposure to ambient atmosphere for a few minutes, a similar Al strip is deposited on top of it forming with the first one a cross-like structure. The resulting impedance is in the kΩ range. The resistance of the junction depends on the thickness of the oxide layer which in turn is dependent on the method of oxidation including the temperature and length of time of exposure to oxygen. Controlled oxidation process can be used to obtain lower impedance.

The output of the argon laser, which is tuned to operate on a single line, is focused to a spot size of 5 microns on the junction. A mechanical chopper placed at the focus of two equal achromatic confocal lenses generates 60 μsec pulses with a rise time of 2 μsec and a duty cycle of about 20. The junction response at the beginning of the laser pulse was obtained by

linearly extrapolating responses taken at 10 μsec and 50 μsec respectively after the start of the pulse. A boxcar integrator with 5 μsec gate width was used to average these data. In this way, the signal across the junction due to the slow laser-induced thermal effects are subtracted. The thermal signal originates from a bolometric process which is nearly proportional to the bias voltage across the junction. In fact, this signal becomes dominant and larger than the photoemissive signal for bias voltages exceeding about 0.1 volt.

The photoemissive signal appears across the junction as a voltage pulse with a rise and decay time following that of the incident laser pulse. This signal is observed only if the laser is focused at the edge of the junction where the oxide is exposed. The slow bolometric effect, however, is observed as long as the laser is focused on the junction or anywhere within a few microns of the junction. This effect is due to heating of the junction causing a decrease of the tunneling impedance.[20] This observation is in general agreement with the types of signals reported in Reference 1.

A journal article based on this work is in preparation and should be submitted for publication in the near future.

REFERENCES

1. S. J. Green, J. Appl. Phys., 42, 1166 (1971).

2. S. P. Kwok , G. J. Haddad and G. Lobov, J. Appl. Phys., 42, 554 (1971).

3. S. M. Faris, T. K. Gustafson and J. C. Wiesner, IEEE J. Quantum Elect., 7, 737, (1973).

4. C. C. Bradley and G. J. Edwards, IEEE J. Quantum Elect., 7, 548 (1973).

5. A. Sanchez, S. K. Singh and A. Javan, Appl Phys. Letters, 21, 240 (1972).

6. L. O. Hocker, A. Javan, Phys. Letters, 26A, 255 (1968).

7. V. Daneu, D. Sokoloff, A. Sanchez and A. Javan, Appl. Phys. Letters, 15, 398 (1969).

8. D. Sokoloff, A. Sanchez, R. M. Osgood and A. Javan, Appl.Phys. Letters, 17, 257 (1970).

9. D. M. Evenson, J. S. Wells, F. R. Peterson, B. L. Davidson and G. W. Day, Appl. Phys. Letters, 22, 192 (1973).

10. D. A. Jennings, F. R. Peterson and K. M. Evenson, Appl. Phys. Letters, 26, 510 (1975).

11. L. Matarrese and K. M. Evenson, Appl.Phys. Letters, 17, 8 (1970).

12. S. Y. Wang, S. M. Faris. D. P. Siu , R. K. Jain and T. K. Gustafson, Appl. Phys. Letters, 25, 493 (1974).

13. J. Giaver, Tunneling Phenomena in Solids, Edited by Burstein, Lundquist, (New York: Plenum Press), 1969. See page 21.

14. M. T. Ludwick, Indium, (New York: Indium Corporation of America), 1959, See particularly page 148.

15. T. K. Gustafson, R. V. Schmidt and J. R. Perruca, Appl. Phys. Letters, 24, 620 (1974).

16. S. Faris, T. K. Gustafson and J. Wiesner, IEEE J. Quantum Elect., 9, 737, (1973).

17. S. Y Wang, S. M. Faris, D. P. Siu, R. K. Jain and T. K. Gustafson, Appl. Phys. Letters, 25, 493 (1974).

18. Bor-long Twu and S. E. Schwarz, Appl Phys. Letters, 25, 595 (1974).

19. A. J. Braunstein, M. Braunstein and G. S. Picus, Appl. Phys. Letters, 8 (1966).

REFERENCES (CONTINUED)

20. R. Stratton, J. Phys. Chem. Solids, 23,1177 (1962). The tunneling conductance per unit area is $G(T) = G_o \frac{x}{\sin x}$ where $G_o = G(T=0)$ and $x = \frac{\pi LkT}{\hbar}\sqrt{\frac{2m}{\phi}} = \frac{1.023\ \pi LkT}{2\sqrt{\phi}}$ for a trapezoidal barrier model. For $x \ll 1$ (otherwise thermionic emission would take place rather than tunneling) we have that the corresponding resistance depends on T as

$$R(T) = \frac{1}{G(T)} = R_o \frac{\sin x}{x} \approx R_o \left(1 - \frac{x^2}{6}\right)$$

for $L = 13$ Å, $\phi = 2$ eV

and $T = 300°K$ we have $x^2 = .13$ and $\frac{\Delta R}{R} = -\frac{x^2}{3}\frac{\Delta T}{T} = -1.45 \times 10^{-4}\,\Delta T$

so that if $T = 70°K$, then $\frac{\Delta R}{R} \approx 10^{-2}$